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The scope of this research project is to derive an analytical approach to target detection and localization at highfrequency bands using multipath propagation. The target is unseen directly by the antennas (both transmitter TX and receiver RX), or out of the Light-Of-Sight (LOS) area, as being covered by the obstacles such as walls or buildings. This analysis is verified through the development of a 3D ElectroMagnetic (EM) model which is based on a combination between a RayTracing (RT) technique (Shooting and Bouncing Ray-tracing SBR) and the asymptotic method Uniform Theory of Diffraction (UTD).

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"Analytical approach to target detection and localization at high-frequency bands using multipath propagation"

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Abstract:

In the scope of this research project, we derive an analytical approach to target detection and localization at high–frequency bands using multipath propagation. The target is unseen directly by the antennas (both transmitter T_X and receiver R_X), or in other words, out of the Light-Of-Sight (LOS) area, as being covered by the obstacles such as walls or buildings. This analysis is verified through the development of a 3D ElectroMagnetic (EM) model which is based on a combination between a Ray–Tracing (RT) technique (Shooting and Bouncing Ray-tracing – SBR) and the asymptotic method Uniform Theory of Diffraction (UTD).

This EM model is useful not only in elucidating the mechanisms of ray propagation through an observed project, but also in evaluating the amplitude and the phase of any point in the far–zone field above the ground. The received far–field is calculated by taking into account all the main interactions involved in outdoor EM propagation that are multiple reflections and diffractions. However, this model still validates for indoor propagation. From this field, we can then detect and predict precisely the position of the target located inside the considered area. Another application of the model is to generate data for Synthetic Aperture Radar (SAR) synthesis in order to evaluate any imaging algorithms. Moreover, the proposed method must give a computational time much faster than any other existing

commercial software (i.e. XGtd®, CST) by closing in a hybrid RT method.

Introduction:

Radar sensing through obstacles, i.e. walls and doors, using microwaves is becoming an effective means supporting a wide range of civilian and military applications. Compared to other radar applications, the detection and localization of a target lodged in a medium is an important problem in wave sensor imaging with many challenges. Ambiguities and inaccuracies in obstacles, for example, are due to the presence of non-uniform walls, multiple walls. It is highly desirable to detect, locate, and classify a variety of hidden targets, moving or stationary, covered in small spaces and in the presence of multipath propagation. Among all known mapping methods, Synthetic Aperture Radar (SAR) differs by its active operational mode. In other words, SAR makes possible to illustrate observed areas with different backscattering characteristics of electromagnetic (EM) waves and offers fundamental advances in geometric resolution. Further applications of SAR image processing can be used for many civil applications such as infrastructure development, weather monitoring and vehicle tracking. In addition, in this kind of application, UltraWideBand (UWB) radars as the special kind of wireless sensor networks allow localize and track authorized or unauthorized targets with advantage in critical environments or under hindered conditions.

Last but not least, the computational time is especially important in EM modeling. The faster the information retrieval process is, the more effective the actions to reach required objectives. This information can be employed for many uses such as infrastructure development planning, environment protection, and traffic surveillance, etc.

With these above reasons, we are motivated to introduce a new approach to the target detection and positioning in an observed area. The multipath technique, such as multiple reflections and diffractions, is used as the core content of this proposed project.

Approach, Experiment, Results and Application:

<u>1. Approach</u>

As mentioned, the proposed method is based on a combination between a RT technique and the asymptotic method UTD with the strong focus on multipath propagation mechanisms such as multiple reflections and diffractions. In details, by coherent integrating the backscattering signal, we propose a 3D propagation model that is useful not only in explaining the mechanisms of wave propagation

through the observed area, but also in determining the amplitude and the phase of any given point in the far-zone above the ground.

RT technique: A RT algorithm is used to determine the geometrical paths of rays inside the illuminated area. Rays are first traced from the source points to the project. When they intercept a facet or the ground, they are specularly reflected and continue to be delineated up to the maximum number of reflections NR which is defined in advance or when they hit the study area boundary. However, in order to integrate all the diffraction effects on the wall edges where the field becomes discontinuous, the intervals between rays should be reduced and as a consequence increase computing time. To avoid it, we develop a hybrid RT method which can refine the ray mesh with the aim of including diffraction effects due to the edges of walls. This adaptive subdivision adjusts the distance between two adjacent rays following different paths through the geometry (i.e., they intercept the margin area of a wall; it means that we can generate a tertiary ray between the two previous ones which might be intercepted by the edge).

UTD method: The main advantage of the UTD method is that each completed ray path from the source to the observer corresponds to a physical scattering mechanism, such as single reflection (R), diffraction (D), double reflections (R-R), reflection-diffraction (R-D) …

Considering a reflection at a point O, the reflected field at a point M (after reflection) is obtained as the sum of two components, vertical (v) and horizontal (h) to the reflection plane, which are functions of the transmitted field, the reflection coefficients and the propagation delay. If we assume that the harmonic time dependence is $e^{j\omega t}$, the reflected field is then given by:

$$\begin{pmatrix} E_v^r(M) \\ E_h^r(M) \end{pmatrix} = \begin{pmatrix} R_v & 0 \\ 0 & R_h \end{pmatrix} \begin{pmatrix} E_v^i(O) \\ E_h^i(O) \end{pmatrix} \frac{e^{-j\vec{k}_r\overrightarrow{OM}}}{\|\overrightarrow{OM}\|} \tag{1}$$

where R_v, R_h are the Fresnel vertical and horizontal reflection coefficients. Thus,

$$\vec{E}^r(M) = E_v^r(M)\vec{v}_r + E_h^r(M)\vec{h}_r \tag{2}$$

In the case of diffraction at a point O (the intersection of a ray with a building edge), the formulation of the diffracted field at a point M (after diffraction) is expressed by using the UTD and given by:

$$\begin{pmatrix} E_v^d(M) \\ E_h^d(M) \end{pmatrix} = \begin{pmatrix} D_v & 0 \\ 0 & D_h \end{pmatrix} \begin{pmatrix} E_v^i(O) \\ E_h^i(O) \end{pmatrix} \frac{e^{-j\vec{k}_r\overrightarrow{OM}}}{\|\overrightarrow{OM}\|} \tag{3}$$

where D_v, D_h are the heuristic vertical and horizontal UTD coefficients of diffraction. Thus,

$$\vec{E}^d(M) = E_v^d(M)\vec{v}_d + E_h^d(M)\vec{h}_d \tag{4}$$

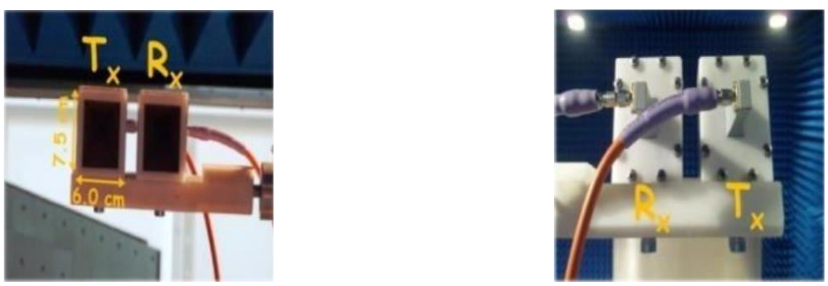
Finally, the total EM field at a given point (the receiver) will be obtained after some mechanisms of

multiple reflections or diffraction(s)-reflection(s) or reflection(s)-diffraction(s). In this project, we will also consider the impact of number of reflections N_R and diffractions N_D on the target detection capacity.

2. Experiments and Results

We have tested the approach method with both numerical and experimental results. According to that, in the anechoic chamber, we used two identical UWB antennas (BBHA 9170) as the transmitter T_X and the receiver R_X. The antenna capture surface is 7.5cm x 6.0cm. They are put side-by-side at a height H(m) and inclined its normal an angle α(°) compared with the ground. The distance between the centers of two antennas is 7.5cm, so that a small bistatic effect might be considered. The measured frequency-band is comprised from 33GHz to 37GHz (Ka-band) with a step of 5MHz. In this frequency band, the main beamwidth of the antenna at -3dB is 13°×15°.

In the first configuration, the two antennas are inclined 18° compared with the ground. After that, we put a 1.5m high metallic wall at the distance of 1.5m from the two antennas. It is obviously that the Light Of Sight (LOS) is at 2.25m far from the wall.



(a) front view (b) back view

Fig.1 Bistatic UWB radar system: transmitter (T_X) and receiver (R_X)

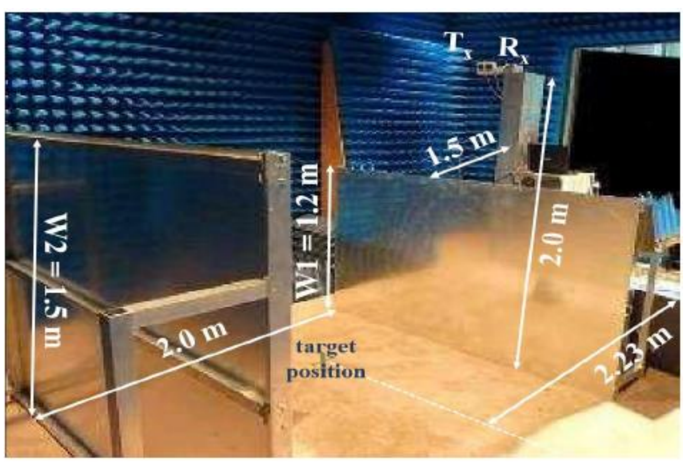


Fig.2 Configuration setup for experimental tests.

Figure 3 below shows the range profiles retrieved from the measurement and the simulation. Each received ray is characterized by its three complex electric field components E_x, E_y and E_z. These components are then projected on two polarizations of the receiver, vertical (v) and horizontal (h). By the fact that when we change the operating frequency, rays bear the same interactions, except the phase of the field will be changed. Hence, we consider each case for only one frequency (we choose here 35 GHz) and then we vary the frequency to get different phases. After all, an Inverse Discrete Fourier Transform (IDFT) is used to get the amplitude of the range profile.

It can be easily seen that we are succeeded in recapturing all the peaks appeared in the measurement by using our model. The first two peaks (1) and (2) are due to the direct diffractions on two walls W1 and W2. Meanwhile, the next five peaks (4, 6, 8, 10 and 12) correspond to the multi-bounces between walls (see Table I). We also conducted the discrepancies between two data in the table. These can be explained by we treat only the main lobes of both antennas.

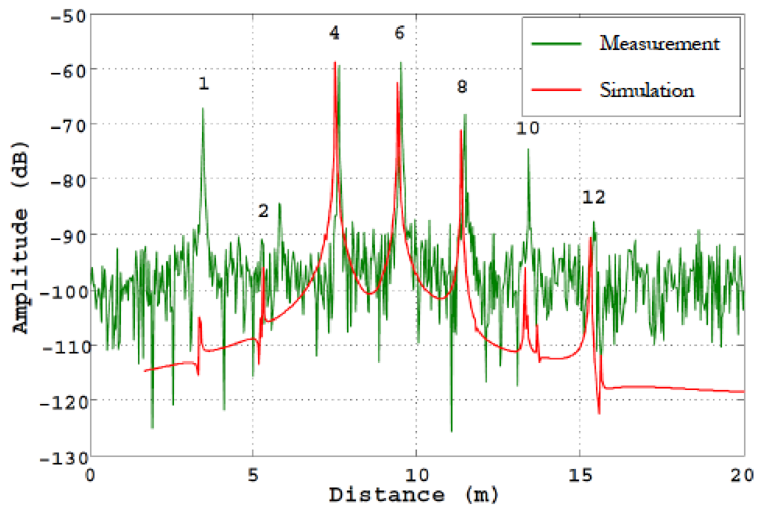


Fig.3 Range profile comparison between measurement and simulation.

Peak number	(1)	(2)	(4)	(6)	(8)	(10)	(12)
Measurement (m)	3.45	5.25	7.61	9.53	11.48	13.42	15.41
Simulation (m)	3.34	5.21	7.50	9.41	11.36	13.35	15.34
$\Delta\partial$ (m)	0.11	0.04	0.11	0.12	0.12	0.07	0.07

Table I. Wall peak positions comparison

Next, we used a 1-in-1 metallic corner reflector sized 22.8cm as the target. It should be noted that the open angle 1 is faced to wall W1. Once again, figure 5 shows the range profiles for the measurement and the simulation in this comparison. As we can see that beside all the peaks due to walls found in the first case, all other peaks regarding to target appearance can also be detected in our

model (peaks numbered 3, 5, 7, 9 and 11).

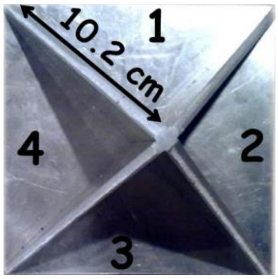


Fig.4 The 4-in-1 metallic corner reflector.

Nonetheless, there are still some peaks that the model cannot retrieve (i.e. 5', 6'…). The same explanation with the previous case is conducted. However, we have accomplished to bring back these peaks when extending the side-lobes of the antennas. In contrast, it increases considerably the computation time. The comparison of target peaks' position between the measurement and the simulation is shown in Table II.

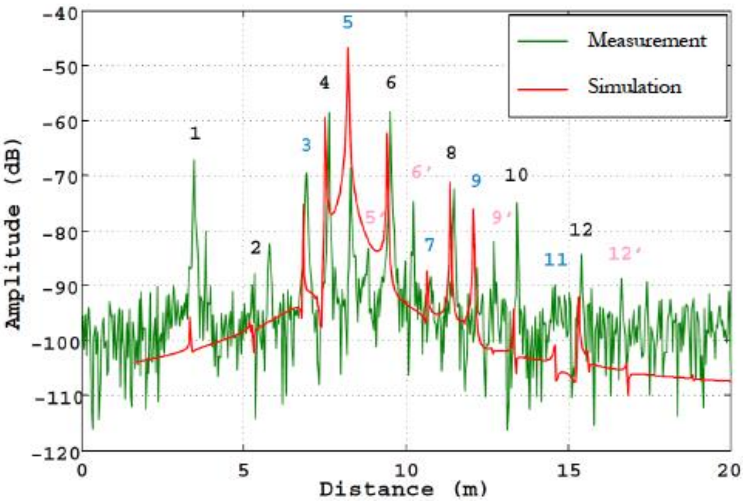


Fig.5 Range profile comparison between measurement and simulation.

Peak number	(3)	(5)	(7)	(9)	(11)
Measurement (m)	6.86	8.29	10.76	13.42	15.41
Simulation (m)	7.50	9.41	11.36	13.35	15.34
$\Delta\partial$ (m)	0.11	0.12	0.12	0.07	0.07

Table II. Target peak positions comparison.

3. Application in SAR synthesis

After being validated, we now apply the proposed model to synthesize data for SAR image evaluation. We always keep the two previous configurations. The radar test-bed system is moved along a rail of 2.0m with the moving step is 1.0cm. The transmit and receive scattered signals are recorded

for every step. At the end, we apply a SAR algorithm in order to reconstruct the configuration images.

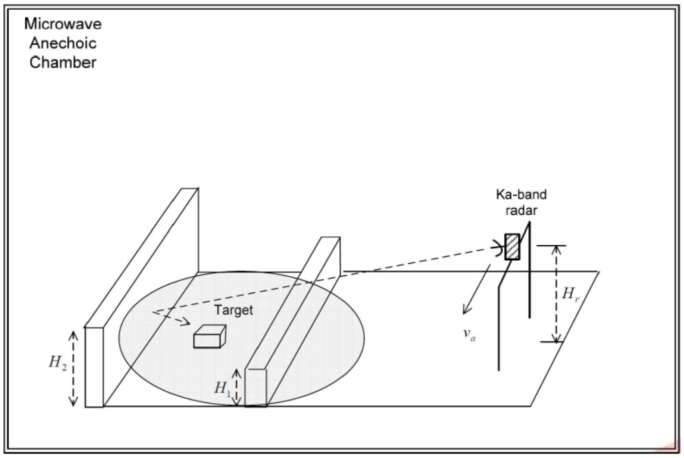


Fig.6 The configuration to generate SAR image.

Configuration 1: Two walls only

As we can see that the multi-bounces between walls produce the ghost images of walls in this case. Different rays in the antenna beam have different incident angles on the second wall W2, which result in different numbers of bounces on the walls, and present a number of ghosts in the image. In this SAR algorithm, we focus on the strongest point (amplitude) to standardize the phase, the second diffraction on wall W2 is thus too weak to be displayed in the image.

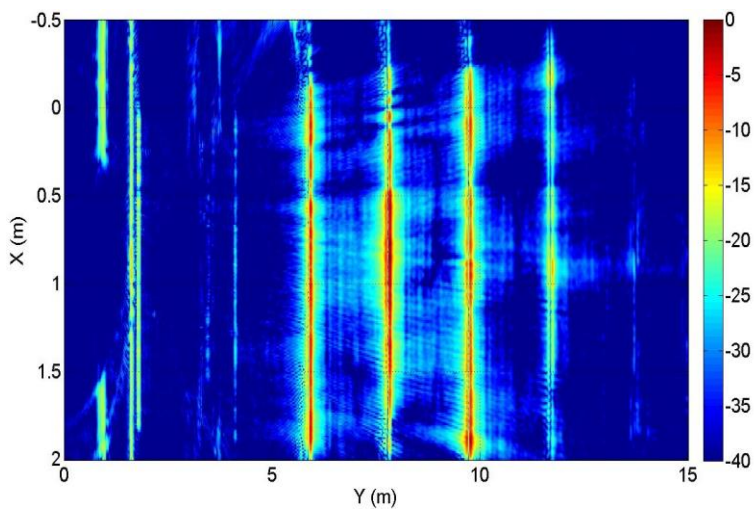


Fig.7 SAR image with two walls only.

Configuration 2: Two walls with a 4-in-1 corner reflector

In the second configuration that a target is bestowed between two walls, we can see the ghost images of target appeared between two walls.

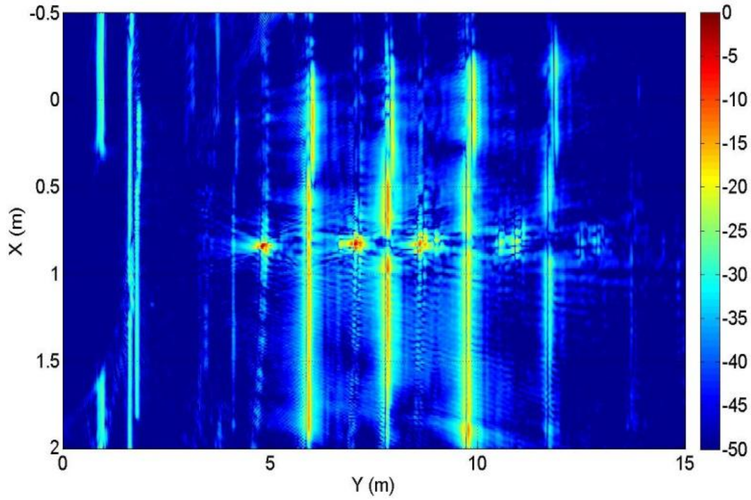


Fig.9 SAR image with a 4-in-1 corner reflector between two walls.

To conclude, we have developed a 3D propagation model to characterize the scattering EM far-field by a scenario. The acquired data from the model can be applied to synthesize information to evaluate SAR imaging algorithms. Hence this would be interest to the remote sensing community.

List of Publications and Significant Collaborations that resulted from your AOARD supported project: In standard format showing authors, title, journal, issue, pages, and date, for each category list the following:

a) papers published in peer-reviewed journals,

b) papers published in peer-reviewed conference proceedings,

c) papers published in non-peer-reviewed journals and conference proceedings,

d) conference presentations without papers,

e) manuscripts submitted but not yet published, and

f) provide a list any interactions with industry or with Air Force Research Laboratory scientists or significant collaborations that resulted from this work.

Attachments: Publications a), b) and c) listed above if possible.

DD882: As a separate document, please complete and sign the inventions disclosure form.

Important Note: If the work has been adequately described in refereed publications, submit an abstract as described above and refer the reader to your above List of Publications for details. If a full

report needs to be written, then submission of a final report that is very similar to a full length journal article will be sufficient in most cases. This document may be as long or as short as needed to give a fair account of the work performed during the period of performance. There will be variations depending on the scope of the work. As such, there is no length or formatting constraints for the final report. Keep in mind the amount of funding you received relative to the amount of effort you put into the report. For example, do not submit a $300k report for $50k worth of funding; likewise, do not submit a $50k report for $300k worth of funding. Include as many charts and figures as required to explain the work.

List of Publications and Significant Collaborations that resulted from your AOARD supported project: In standard format showing authors, title, journal, issue, pages, and date, for each category list the following:

a) papers published in peer-reviewed journals,

None

b) papers published in peer-reviewed conference proceedings,

[1] **Conf. name:** 2015 International Conference on Advanced Technologies for Communication (ATC 2015)

Conf. venue: Ho Chi Minh City, Vietnam

Title: A 3D Model To Characterize EM Far-Field Scattering and Its Applications in SAR Data Synthesis

Date: October 14-16, 2015

[2] **Conf. name:** 2015 IEEE International Symposium on Antennas and Propagation and North American Radio Science Meeting, APS/URSI 2015

Conf. venue: Vancouver, BC, Canada

Title: A 3D Model To Characterize High-Frequency Scattering: Applied To Synthesize SAR Data

Date: July 19-24, 2015

[3] **Conf. name:** IEEE International Geoscience and Remote Sensing Symposium 2015 (IGARSS 2015)

Conf. venue: Milan, Italy

Title: The Detection And Localization Of A Hidden Target Using Ka-Band Bistatic Radar System: Experiments And Simulations

Date: July 26-31, 2015

[4] Conf. name: 2014 Sixth International Conference on Computational Intelligence and Communication Networks (CICSP 2014)

Conf. venue: Hong Kong, China

Title: A 3D Simulation Model for Experimental Analysis from Moving Target Detection and Localization using UWB Radar System

Date: October 19-20, 2014

[5] Conf. name: The 2015 Vietnam-Japan MicroWave (VJMW 2015)

Conf. venue: Ho Chi Minh City, Vietnam

Title: A 3D Propagation Model To Characterize Far-Field Scattering At High-Frequency Bands: Applying In SAR Data Synthesis

Date: August 10-11, 2015

c) papers published in non-peer-reviewed journals and conference proceedings,

[1] Conf. name: The 2015 Vietnam-Japan International Symposium on Antennas and Propagation (VJISAP 2015)

Conf. venue: Ho Chi Minh City, Vietnam

Title: A Simulation Model Applied for Moving Target Detection and Localization using UWB Monostatic/Bistatic Radar System

Date: January 09-10, 2015

d) conference presentations without papers,

[1] Conf. name: The 2015 International Symposium on Electrical-Electronics Engineering (ISEE 2015)

Title: A Model Applied To Target Detection In Urban Areas In Bistatic And/Or Monostatic Radar Mode

Date: 2015/10/30

[2] Conf. name: The 2015 Inter-University Workshop On Electronics and Communications (IUWEC 2015), Ho Chi Minh City, Vietnam

Title: A 3D Scattering Model Applied in SAR Data Synthesis At High-Frequency Bands

Date: 2015/5/29

[3] Conf. name: The 2014 Inter-University Workshop On Electronics and Communications (IUWEC 2014), Ho Chi Minh City, Vietnam

Title: A Scattering Model for Urban Propagation: Application to Moving Target Detection at High-Frequency Bands

Date: 2014/12/19

[4] **Conf. name:** The 2014 Inter-University Workshop On Electronics and Communications (IUWEC 2014), Ho Chi Minh City, Vietnam

Title: Development Of A3D Scattering Model for Urban Propagation Applied in Target Detection And Localization

Date: 2014/4/23

e) manuscripts submitted but not yet published,

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Title: An Analytical Analysis To Target Detection And Localization At High–Frequency Bands Using Multipath Propagation

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Authors: Nguyen Ngoc Truong MINH, Mai LINH, Nguyen Binh DUONG

[2] **Journal Name:** REV Journal on Electronics and Communications

Title:

Date Received: 2016/2/05

Authors: Nguyen Ngoc Truong MINH, Mai LINH, Nguyen Dinh UYEN, Tran Van SU

f) provide a list any interactions with industry or with Air Force Research Laboratory scientists or significant collaborations that resulted from this work.

4. Invited talks (event name, title, date):

[1] **Event name:** The 2016 Vietnam-Japan International Symposium on Antennas and Propagation (VJISAP 2016) - Nha Trang, Khanh Hoa, Vietnam

Title: The Detection And Localization Of A Hidden Target Using Ka-Band Bistatic Radar System: Simulations And Experiments

Date: Feb. 29 - Mar. 01, 2016

[2] **Event Name:** Window On Science Application Package - Dayton, Ohio, US

Title: An Analytical Analysis To Target Detection And Localization At High–Frequency Bands Using Multipath Propagation

Date: 2015/7/14

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